DIII-D Edge, Divertor, and PFC Experiments

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[b]Sandia National Laboratories, Albuquerque

[c]University of Toronto Insitute for Aerospace Studies

[d]University of Wisconsin

[e]General Atomics

[f] University of California, San Diego

[g]FZJ Jülich GmbH/Euratom Institut für Plasmaphysik

[h]Alfven Laboratory, Stockholm, Sweden

[i]Euratom/UKAEA Fusion Association, Culham

[j]Princeton Plasma Physics Lab

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Particle transport is one of DIII-D's research themes (1. Deuterium)

Study the Physics involved with:

1. Plasma fueling (deuterium)

- **--Density control with pumping (Adding new pump in 2005)**
- **--Particle transport in the SOL ("Blobs")**
- **--ELMs transport particles and heat (Scalings, pedestal physics)**
- **--Stochastic boundary can control ELMs (Resonant effect with edge coils)**

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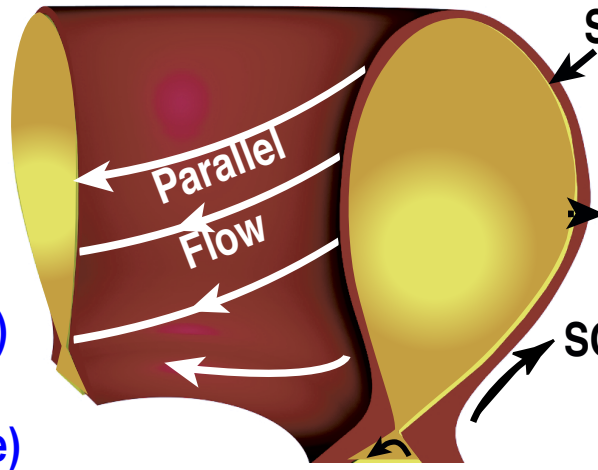
Particle transport is one of DIII-D's research themes (2. Carbon)

2. Impurity Transport - Primarily Carbon in DIII-D:

- Carbon Source (2-d measurements)
- Physical or chemical sputtering (Div. Spectroscopy)
- SOL and divertor transport (Flow in the plasma edge)
- Where is the carbon re-deposited, and what is it's form?
  - (C13 tracer experiments) - (Wampler -- boron, too)



Divertor:
Deposition & Erosion - Sources

- Relevant to ITER because the largest tritium inventory could be co- deposited with carbon layers that have large surface area.

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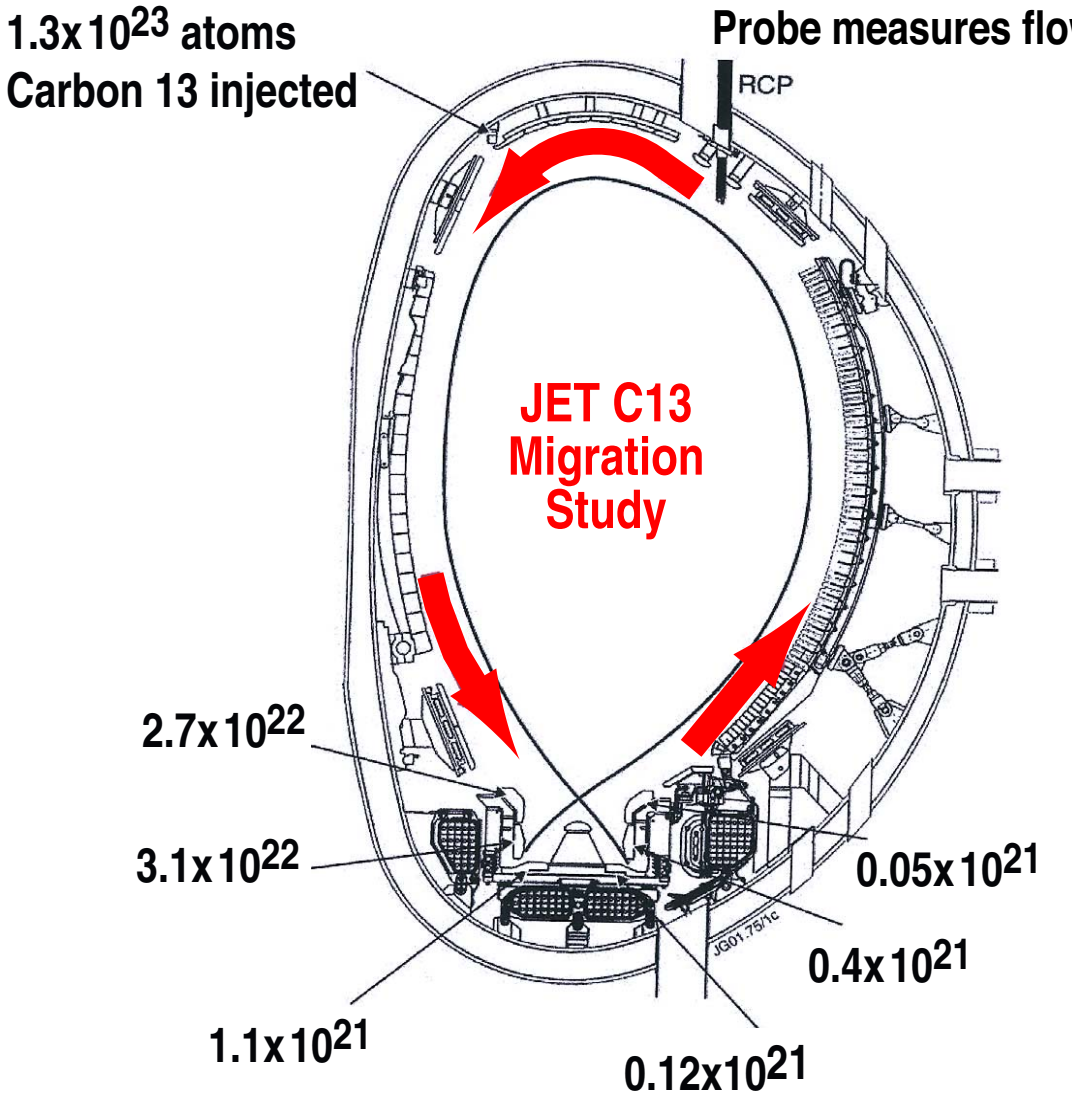
Collaboration with EU labs brought ^{13}C transport to DIII-D



- V. Phillips proposed ^{13}C experiment at DIII-D
- JET, ASDEX, TEXTOR involved in discussions
- ^{13}C was found on the inner wall of the divertor
- D^+ Flow measured at a few poloidal locations on several tokamaks

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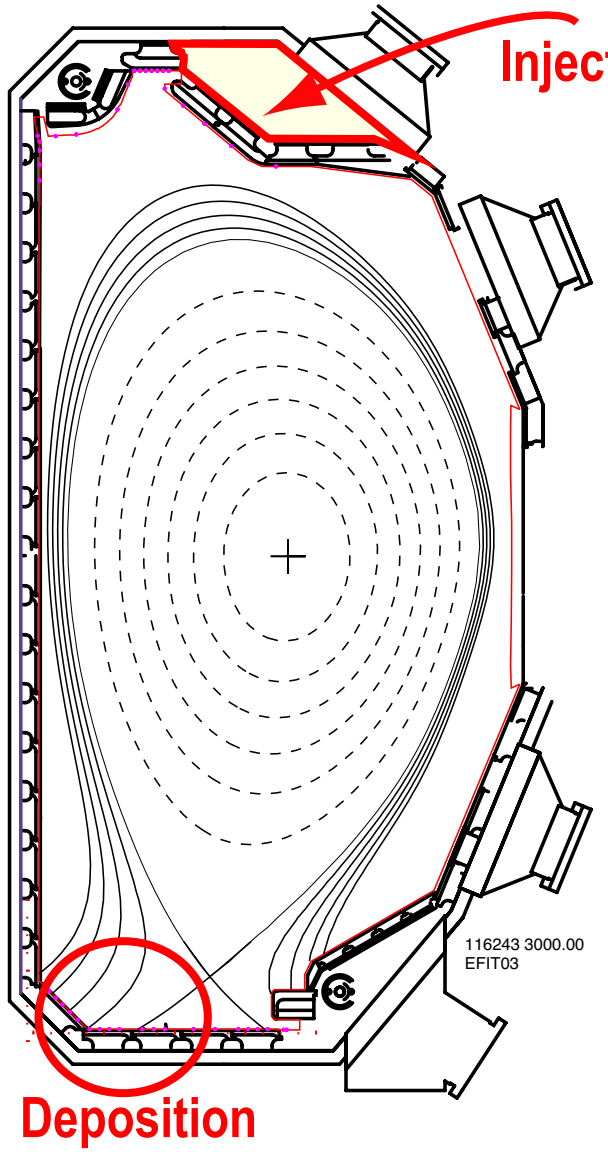
^{13}C injection on DIII-D shows deposition at inner strike point



Summary

- 300 T l of $^{13}CH_4$ was injected (toroidally symmetric) into 22 identical L-mode LSN discharges
- 29 carbon Tiles were analyzed by Nuclear Reaction Aanalysis at Sandia for ^{13}C, for a total of 1255 data points
- ^{13}C was only found inboard of inner strike point
- Data and modeling show that flows are important -- need better diagnostics!

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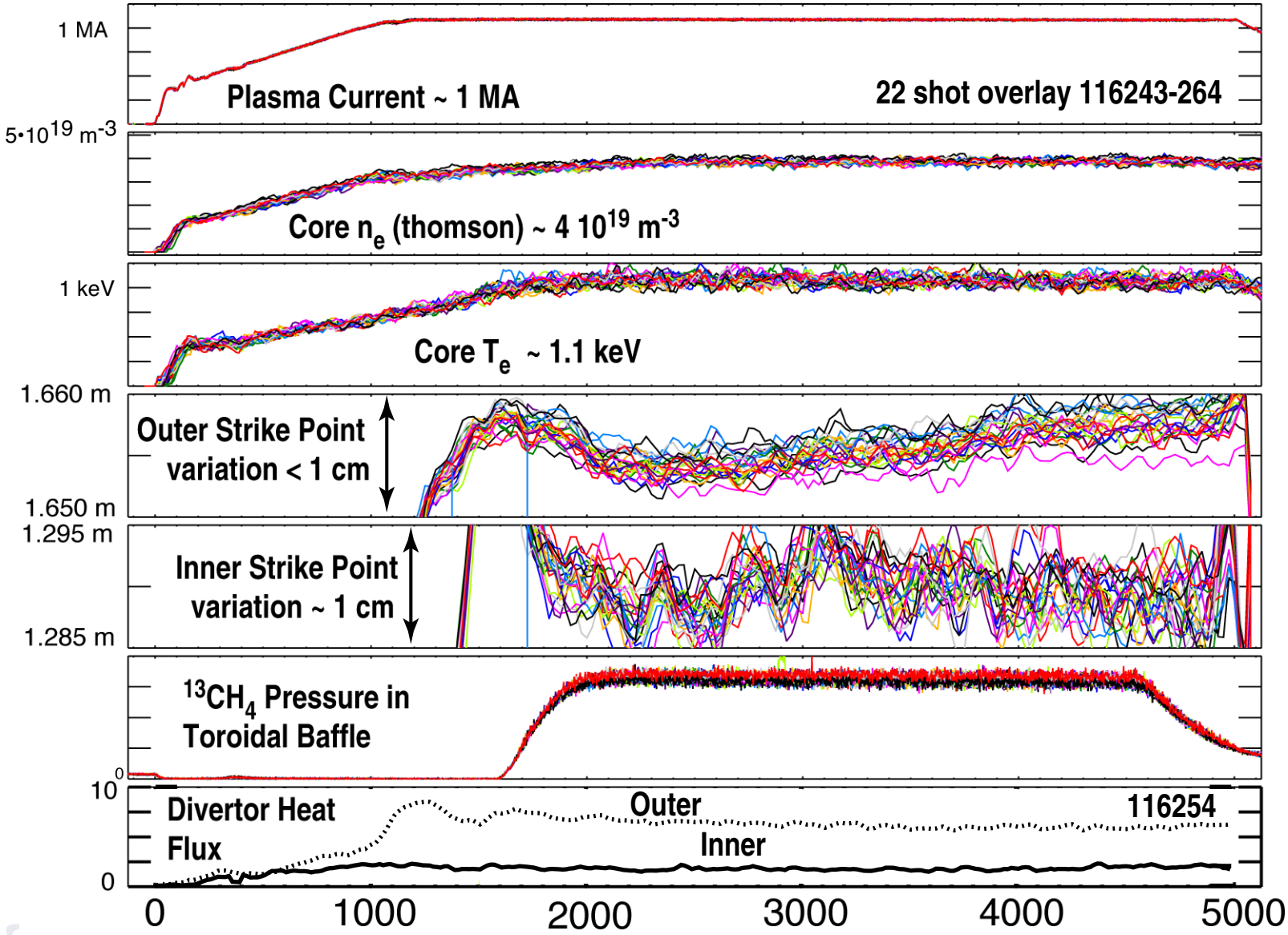
^{13}C was injected into 22 similar L-mode discharges before DIII-D vent



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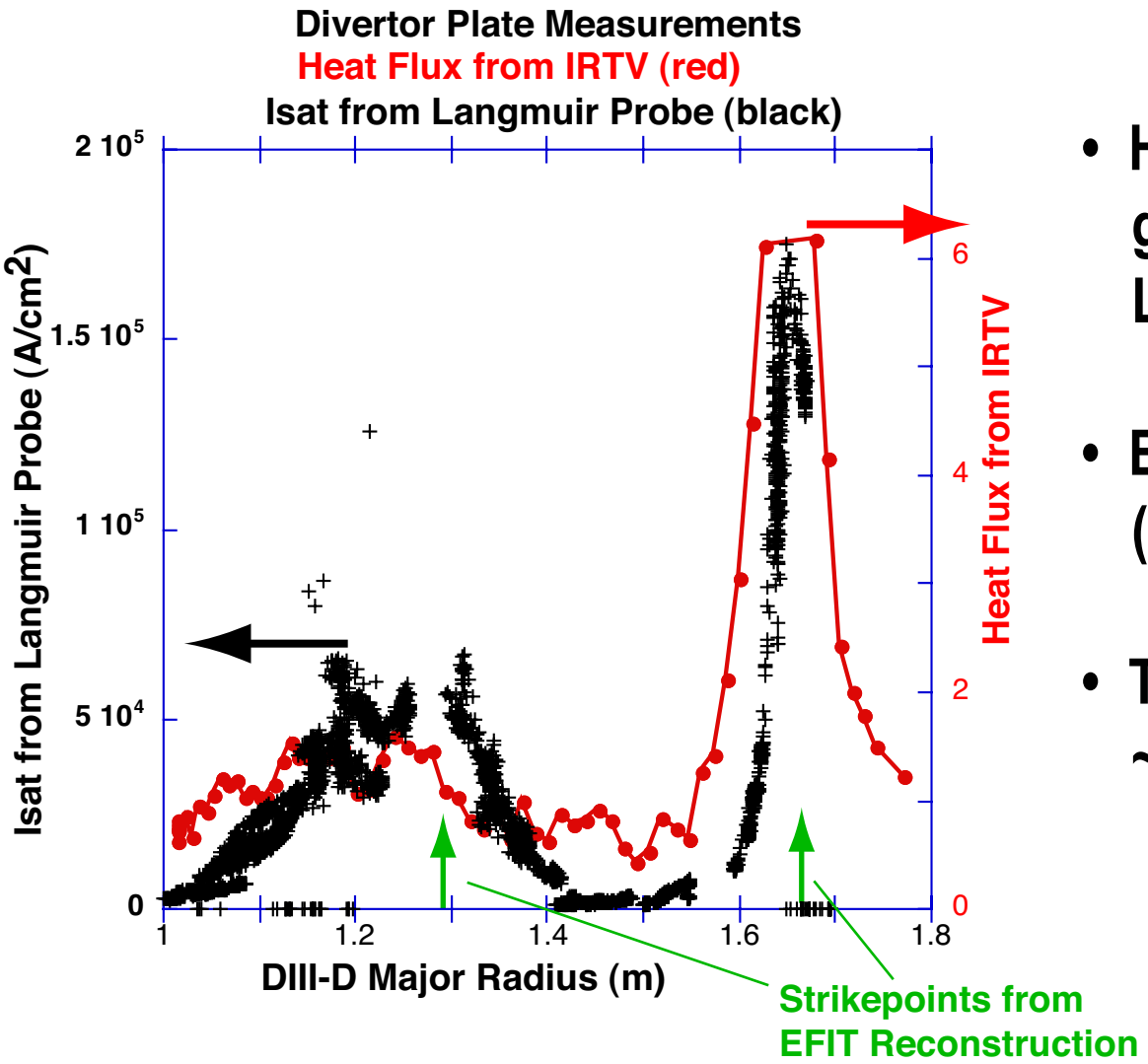
Plasma conditions at the divertor plate are typical of L-mode



- Heat flux and I_{sat} are greater at OSP, typical of L-mode
- B x ∇B drift is down (same at JET, but I_p not)
- Typical EFIT uncertainty ~ 1 cm for strike points

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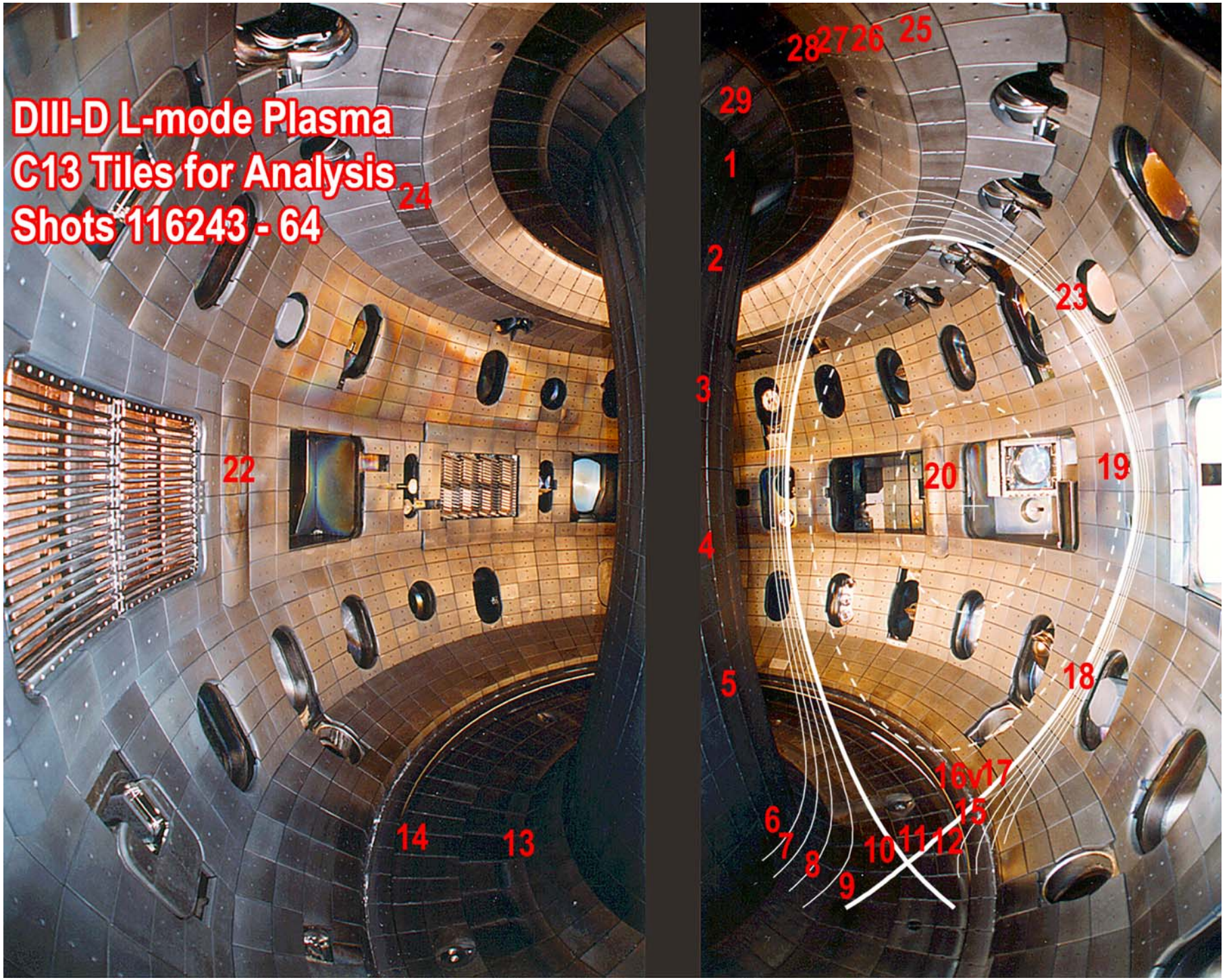
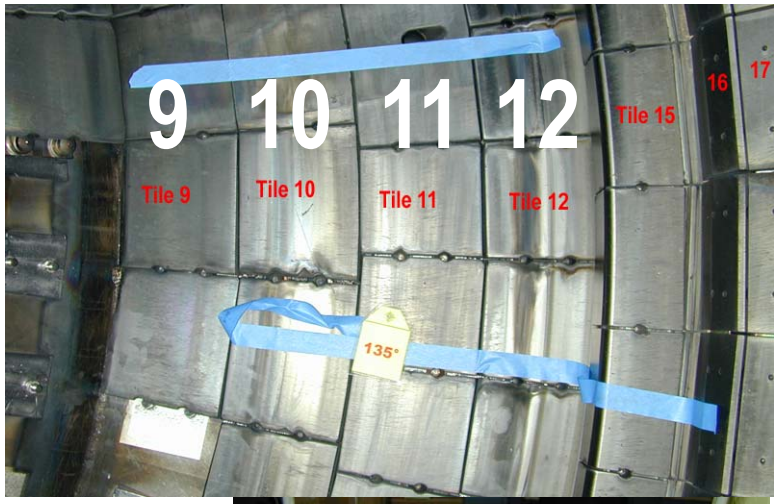
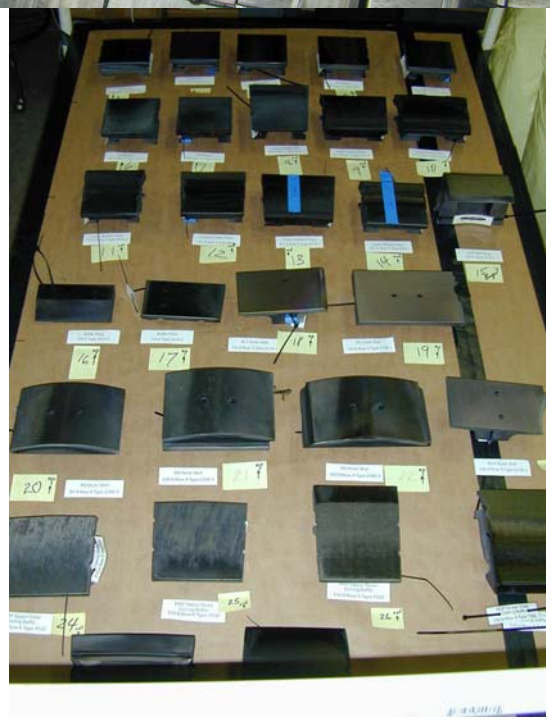
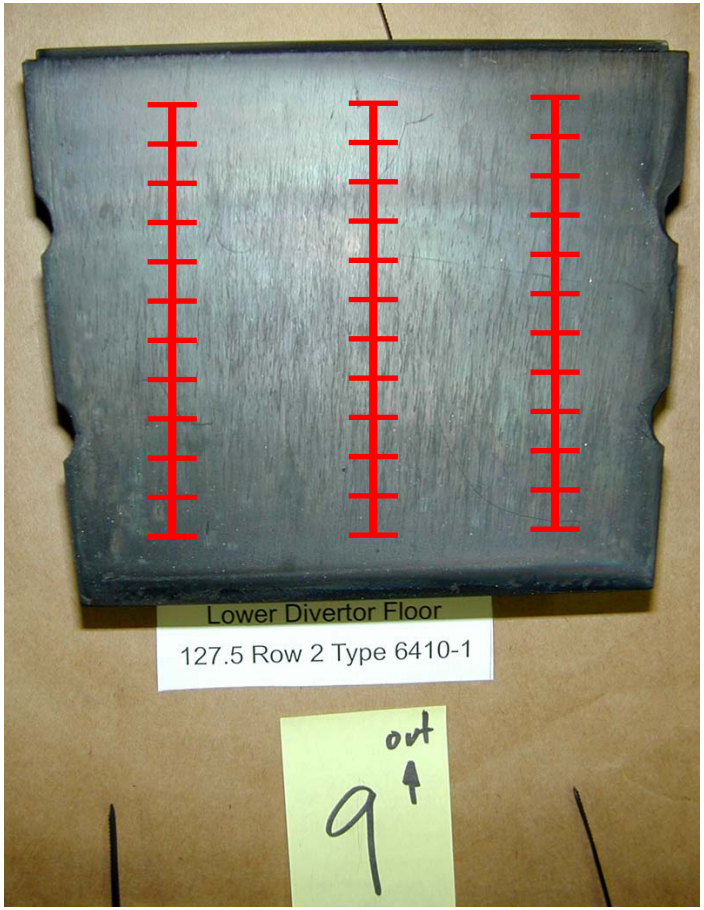

DIII-D L-mode Plasma
C13 Tiles for Analysis
Shots 116243 - 64
24
22
14
13
28
27
26
25
29
1
2
23
3
20
19
4
5
18
16
17
15
6
7
8
9
10
11
12

29 tiles to Sandia for ^{13}C analysis by Nuclear Reaction Analysis







- 3 rows of analysis on each tile at ~1 cm intervals (shown schematically)
- 1255 data points on 29 tiles

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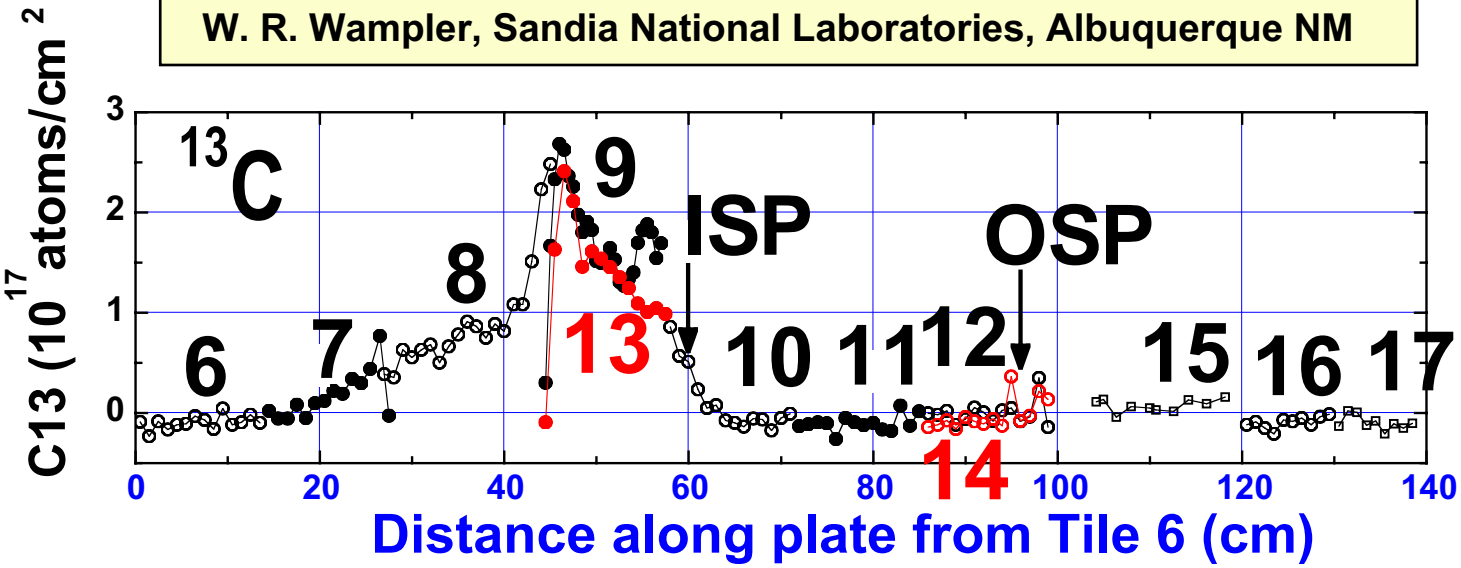
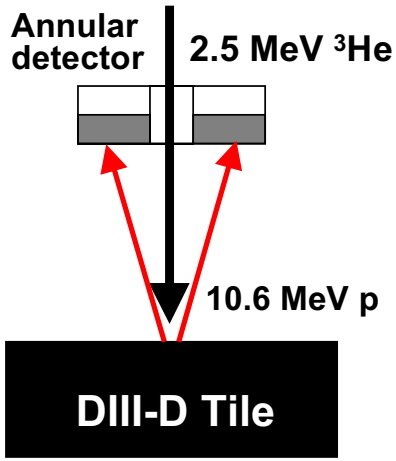
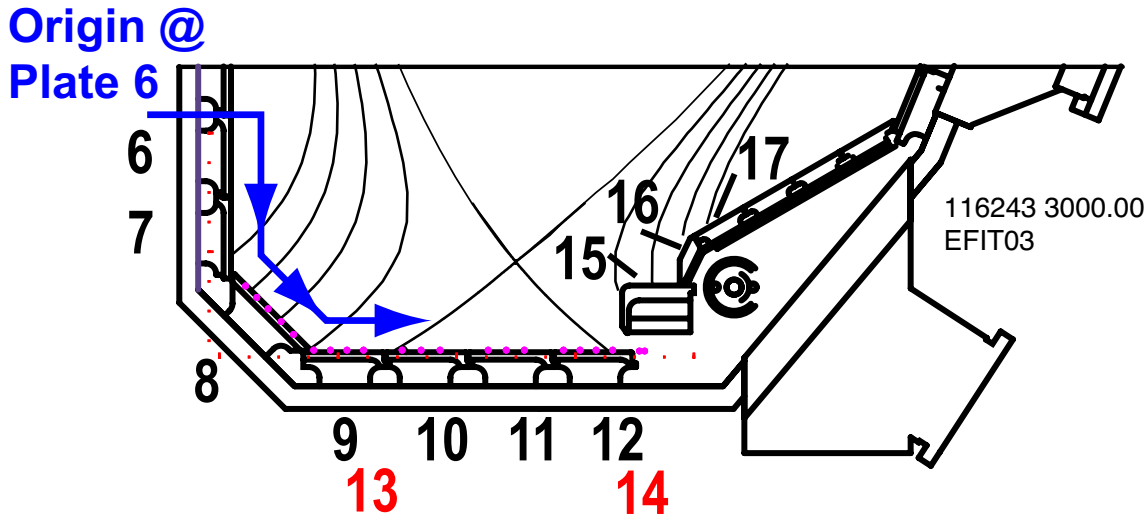
Most of the deposited ^{13}C was inboard of the inner strike point

$^{13}C(^{3}He,p)^{15}N$ nuclear reaction analysis

W. R. Wampler, Sandia National Laboratories, Albuquerque NM







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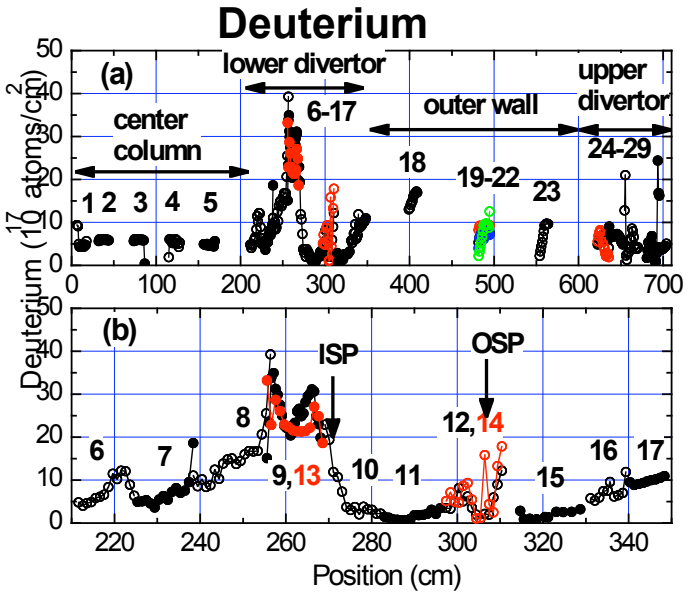
^{3}He NRA also gives boron and deuterium coverage revealing regions of net erosion and deposition.

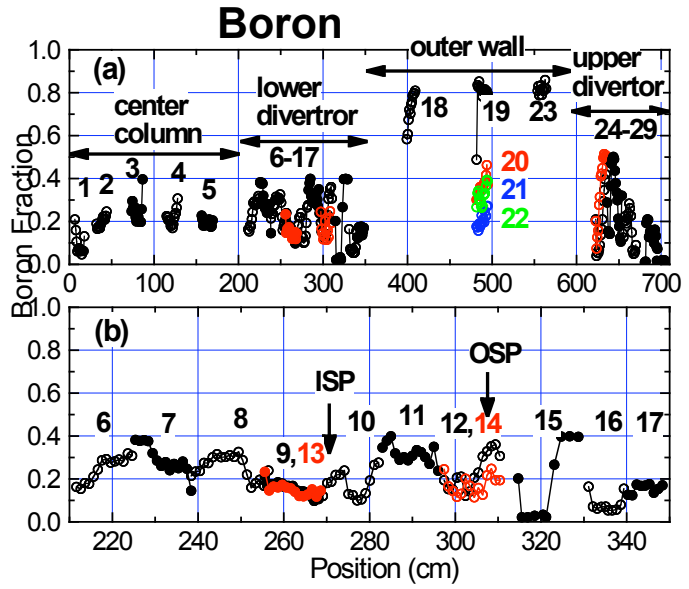
W. R. Wampler

- Boron is deposited to condition the wall (boronization).
- Boron can
  - remain where there is little erosion or deposition (high B, low D)
  - be covered by CD deposition (low B, high D),
  - be removed by erosion (low B, low D).
- The distribution of deuterium and boron near the surface (<2μm) reveals regions of net erosion and deposition from prior operation.

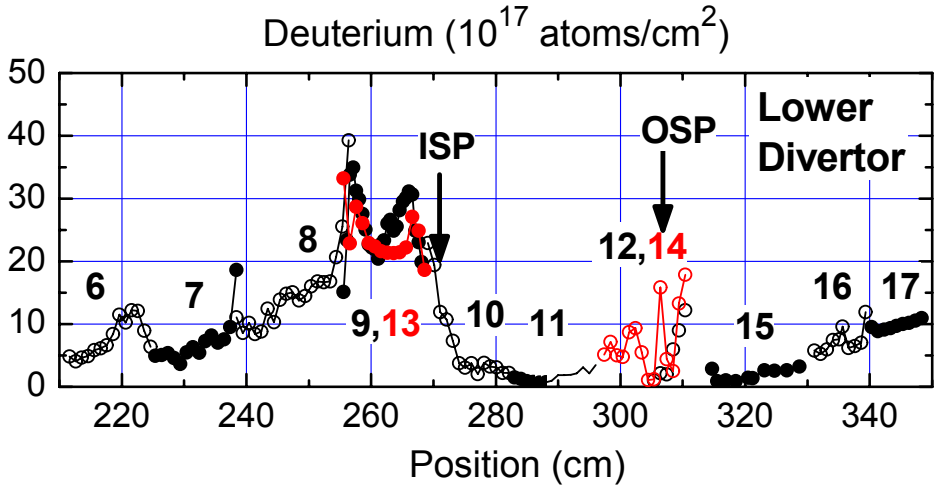
	D	B	
Center column	low	low	erosion
Inner divertor	**high**	**low**	**deposition**
Outer divertor	low	low	erosion
outer wall	low	high	Little erosion or deposition
Rail limiters	low	low-med	low erosion
Upper divertor	low	low-med	low erosion
Private flux region	low	low-med	low erosion

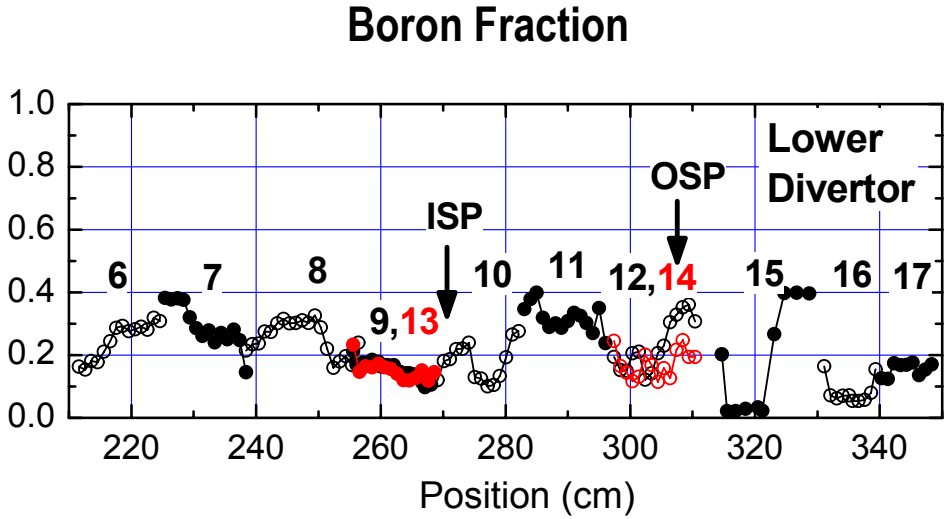
Highest CD deposition at the inner divertor, erosion on outer divertor & center column.





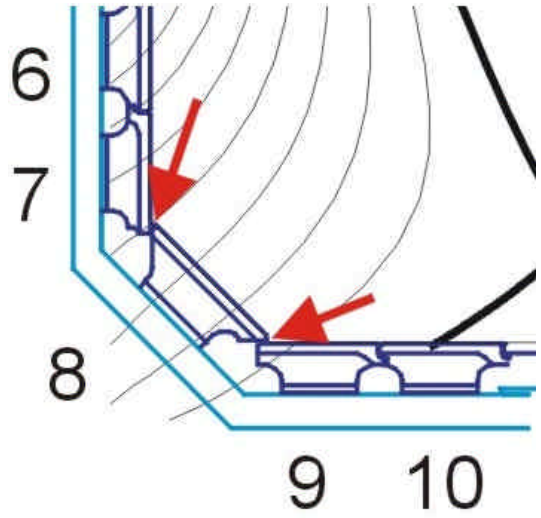
NRA analysis also obtains Deuterium and Boron Distributions

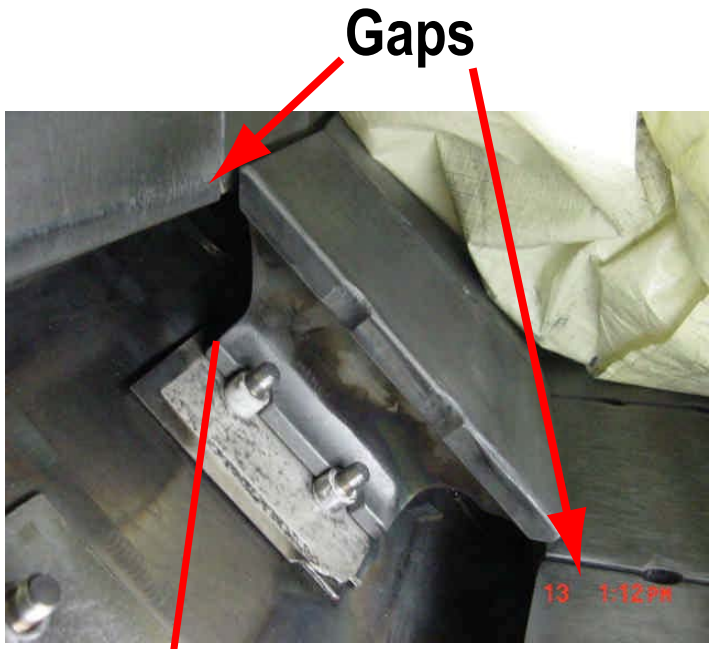




Tritium was found on foot of tile - only tile gap in machine

- DIII-D experience is tritium concentrated on "burned" areas
- Bottom of tile 8 was found to have tritium
- This is the only tile gap (no overlap) in DIII-D; 1-3 mm typical
- This tile had seen several DIII-D run years of (D-D) fusion reactions





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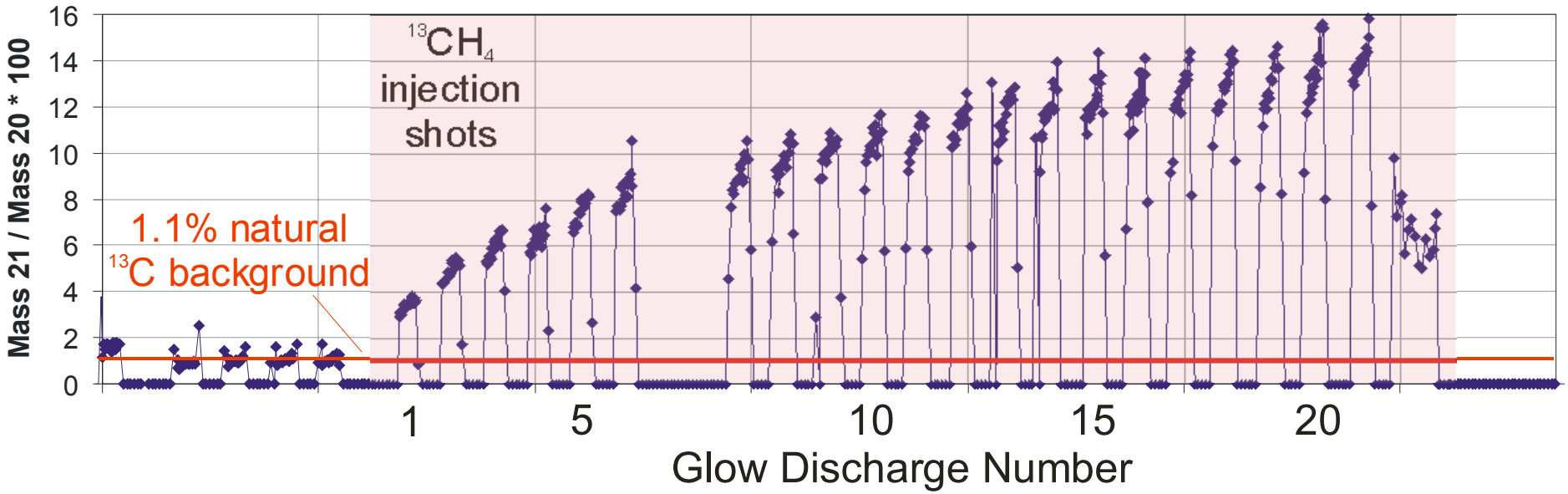
99.5% of injected ^{13}C remains in-vessel after inter-shot He glow discharge cleaning

- Residual Gas Analysis data throughout all 21 glow discharge periods
- Ratio of mass 21/20 indicative of $^{13}CD_4/^{12}CD_4$
- Found to increase to approximate equilibrium after ~16-20 shots



- Direct calibration of RGA results using $^{12}CD_4$ calibrated leak
- ~1.5 torr L of $^{13}CD_4$ lost during GDC, or ~0.5% of injected ^{13}C

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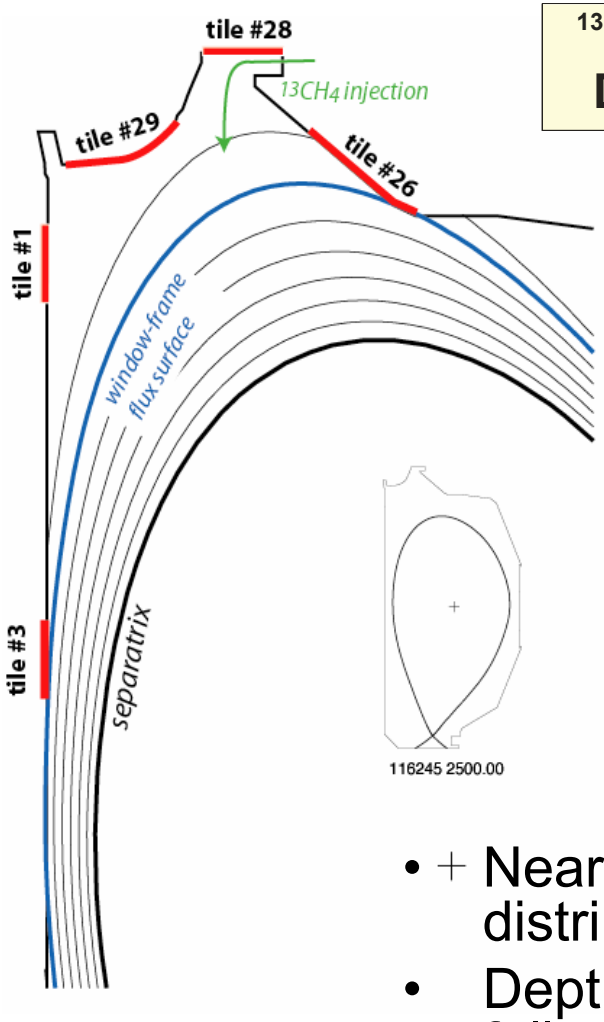
A large portion of the remaining ^{13}C is accounted for in a thin layer near injection outlet and down centerpost



$^{13}C(p,\gamma)^{14}N$ nuclear reaction resonance
D.G. Whyte, University of Wisconsin

- + Near surface (<100 nm) enrichment equal to divertor but distributed over a much larger area
- Depth profiles vary with areas of ion/neutral deposition, follow magnetic field incidence on centrepost
- Preliminary inventory suggests the main wall and upper divertor may contain >40% of injected ^{13}C (Wright, EP1.117)

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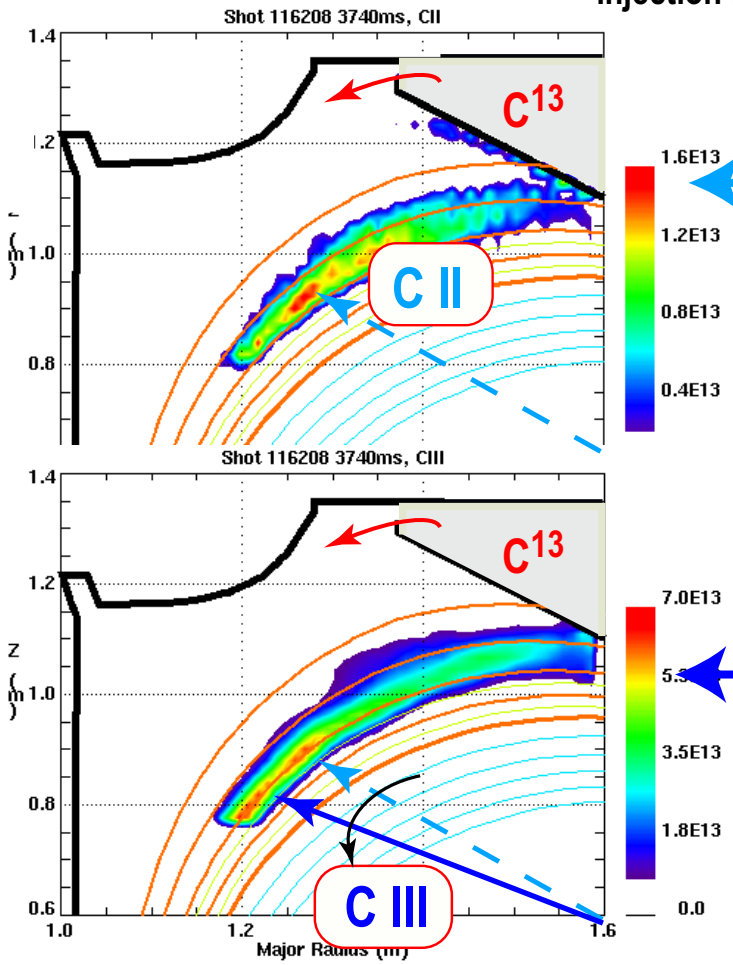
Carbon emission profiles explained by poloidal SOL flow

Toroidally symmetric methane injection from upper plenum



CII emission from tangential camera shows emission close to plenum

CIII emission is farther away poloidally: simple explanation is flow of carbon in the SOL

- Radially varying flow of M ~ 0.4 at separatrix to M ~ 0.1 in SOL (DIVIMP) consistent with data: A. McLean Poster P3-36, Thursday

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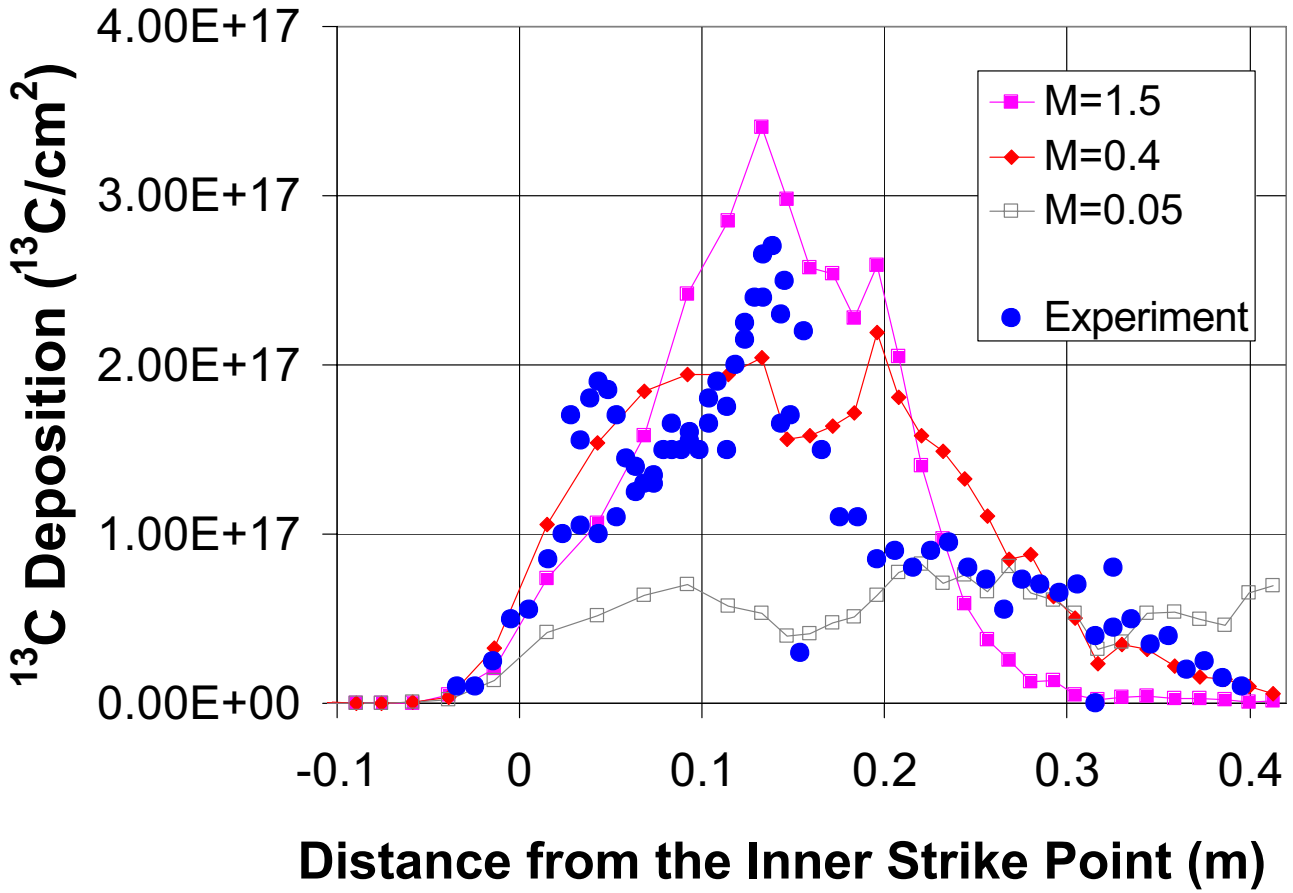
OEDGE + DIVIMP models inner strike point deposition with M~0.4



D. Elder P2 - 11

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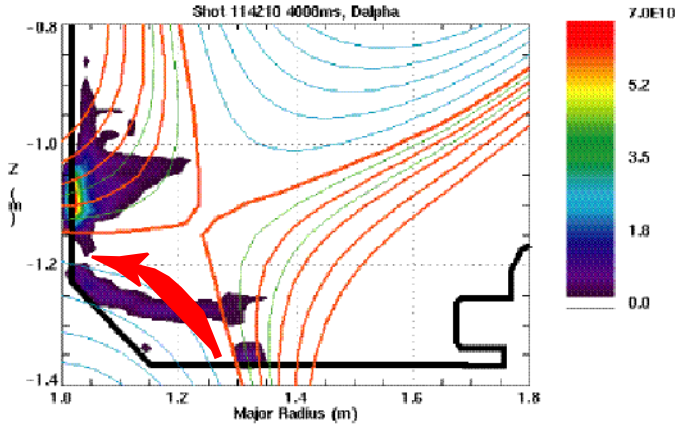
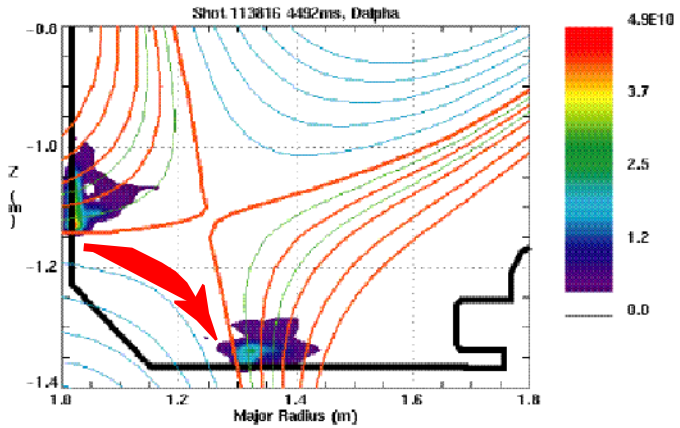
UEDGE modeling shows importance of E x B drifts in divertor (H-mode)

Measured D_α Profile

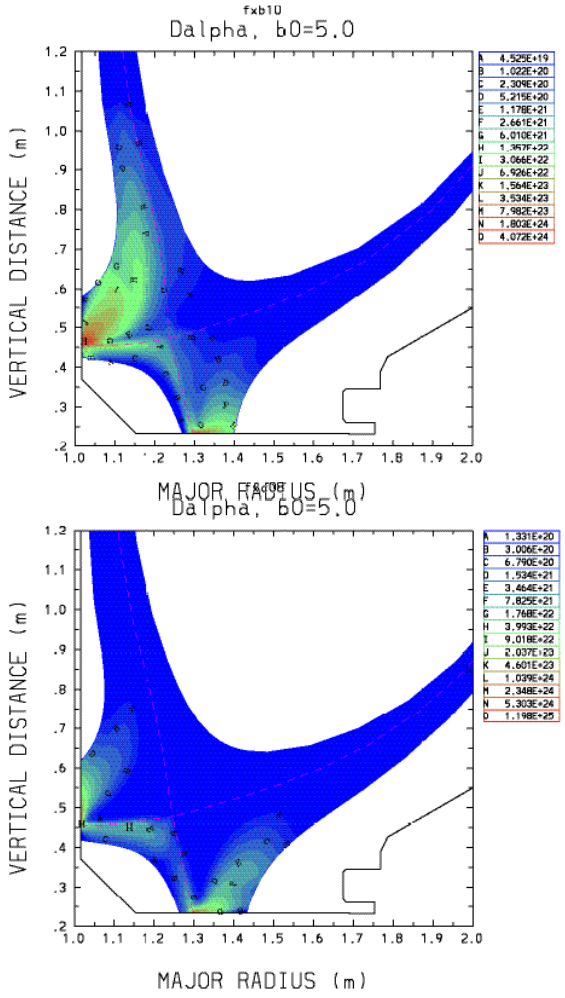


114210
grad-B drift down



113816
grad-B drift up

Modeled D_α Profile



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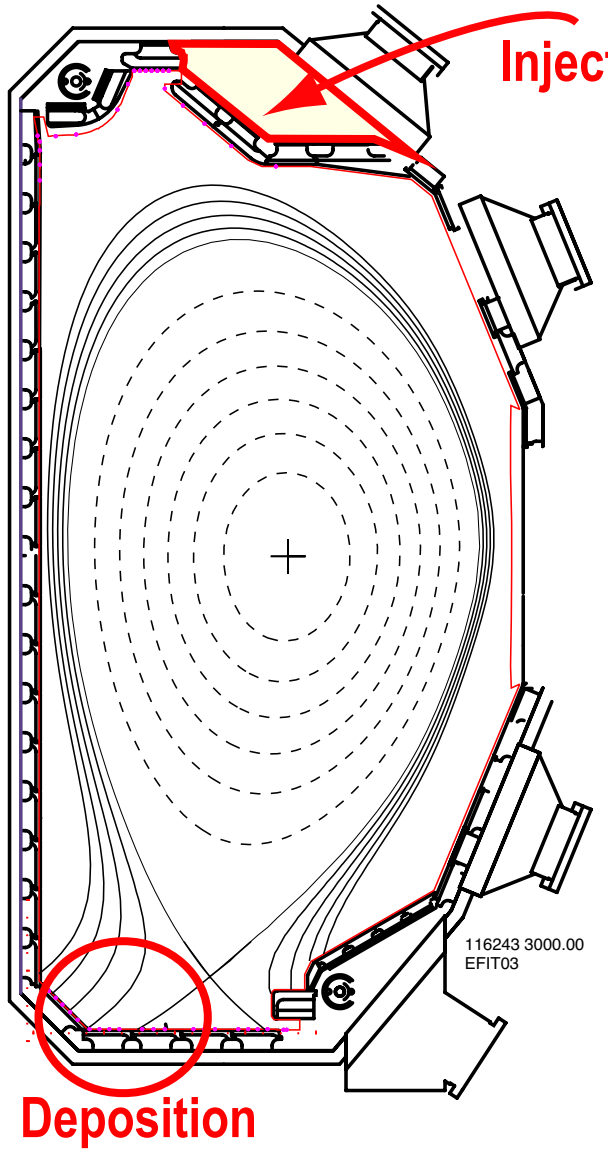
Possible future research directions -- give us some advice!

- Measure 2-D flow patterns in SOL & divertor of ELMing H-mode
  - Laser fluorescence & CER insufficient S/N

- Continue $^{13}CH_4$ experiments -- one a year with lots of analysis!
  - Test removal with oxygen bake
  - Reverse flows by changing the toroidal field
  - Look at ELMing H-mode

- Strive for more real-time measurements
  - New ideas at this meeting
  - Quartz Microbalances in gaps -- must verify gap measurements

^{13}C injection on DIII-D shows deposition at inner strike point



Summary

- 300 T l of $^{13}CH_4$ was injected (toroidally symmetric) into 22 identical L-mode LSN discharges
- 29 carbon Tiles were analyzed by NRA for ^{13}C, for a total of 1255 data points
- ^{13}C was only found just inside inner strike point
- Data and modeling show that flows are important -- need better diagnostics!

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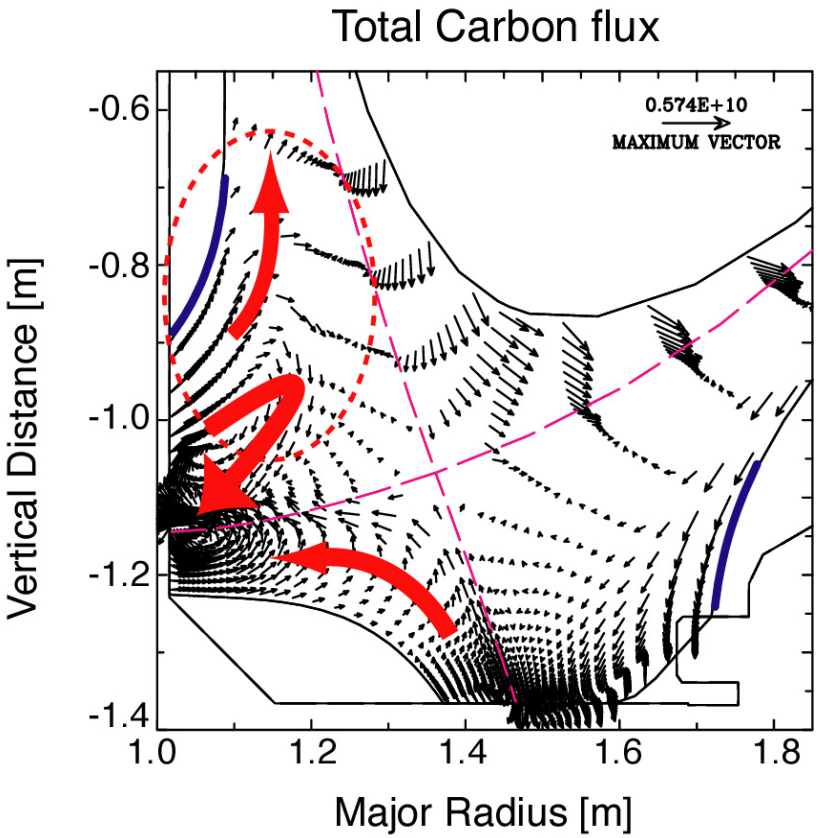
UEDGE: carbon flows at inner strike point reverse direction



- Carbon from outer strike point region/PFR swept to inner plate by **E**x**B** from large E_r near separatrix
- Some redeposition of carbon in vicinity of inner strike point
- Above x-point, low frictional drag on carbon ions
- Leakage of carbon into main SOL/core due to ∇T_i force

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